

REAR-END COLLISION AVOIDANCE ASSIST SYSTEM

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ABSTRACT

Rear-end collisions occur at higher frequency in Japan. The causes of rear-end collisions were therefore investigated. Accident statistics were used to conduct a statistical traffic accident analysis. Simulation was then used to perform an accident analysis on the basis of those studies. The results suggested that many of these accidents were caused by momentary inattention during daily driving. Research was therefore carried out to determine what kind of collision avoidance assist system would be effective for use at such times. The researched system used warning and brake control. The warning timing was set so that it would not interfere with the driver nor lose its impact as a warning. The result was creation of a system capable of contributing to the reduction of rear-end collisions.

INTRODUCTION

In the Advanced Safety Vehicle (ASV) project in Japan which was promoted by the Ministry of Land, Infrastructure and Transport, the corporations involved have proposed a variety of systems using external sensing technology such as radar sensors in order to reduce traffic accidents.

Systems designed to avoid collisions or reduce accident damage using brake control and external sensing technology such as radar sensors to predict collisions with the vehicle ahead have been proposed in the first phase of the ASV project.

The present system concept was defined to assist the driver with accident avoidance. The type of accident target was defined rear-end collisions. This report describes the creation of a system aimed to achieve practical application.

ACCIDENT SUMMARIES

In Japan, overall surveys⁽¹⁾⁽²⁾ of traffic accidents involving injury or fatality in 1997 indicate that approximately 30% of all accidents were rear-end collisions. (Figure 1.).

A survey of the distinctive features of rear-end collisions indicates that most accidents occur when vehicles are cruising at low to

medium speeds (Figure 2.). Figure 3. shows human factor of rear-end collisions. Inattention in the forward direction and other such failures in recognition were a common factor. Figure 4. shows road configuration at rear-end collisions. It was apparent that accidents on straight roads make up approximately 90% of the total, while extremely few accidents occurred on curved roads. Figure 5. shows the status of the other vehicle involved during rear-end collisions. It is apparent that rear-end collisions with stationary vehicles are in the great majority, accounting for approximately 90% of the total. The above accident surveys suggest that the majority of rear-end collisions involve cruising relatively slowly on a straight road. Then, when the driver is delay to recognize the vehicle ahead due to inattention in the forward direction or other reasons, rear-end collisions occur.

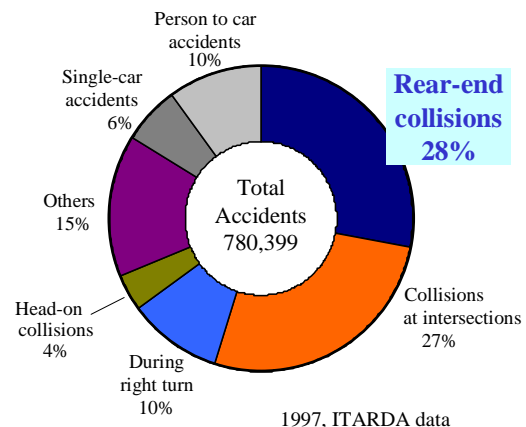


Fig.1 Composition of traffic accidents per year

ACCIDENT CAUSES

Questionnaire Survey

A questionnaire survey was conducted within Honda. The survey targeted people who had actually experienced rear-end collisions and those who had almost experienced such accidents. First, the status of the vehicle ahead was examined. The majority of vehicles ahead were moving vehicles that were being followed from behind (Figure 6.). This finding contradicts Figure 5. Figure 7. shows factors in rear-end

collisions. Delay in recognizing deceleration and unexpected deceleration by the other vehicle were factors in approximately half of the accidents. That is, drivers had not been looking to the side for prolonged periods, and were aware that a vehicle was ahead. However, their attention lapsed, then accidents occurred. This is thought to be what made them either collide with the vehicle ahead or feel they had almost collided with the vehicle ahead.

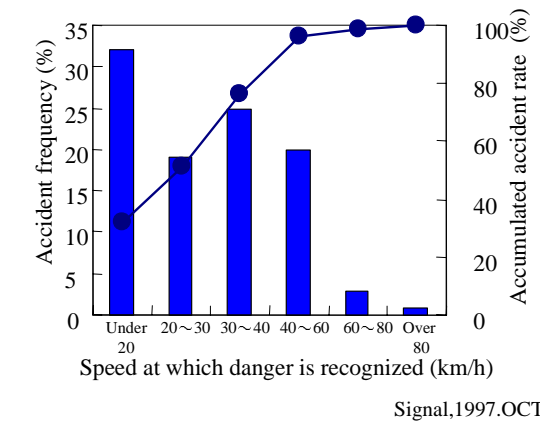


Fig.2 Frequency and accumulated rate of rear-end collisions in relation to the speed at which danger is recognized

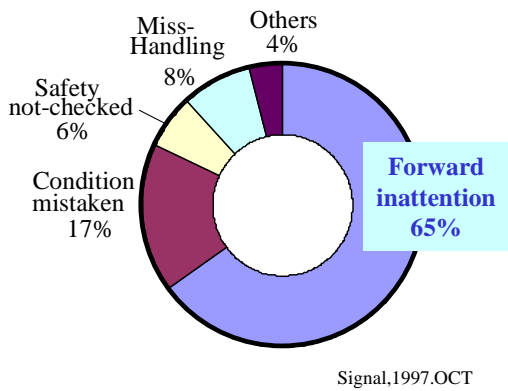


Fig.3 Factor in rear-end collisions

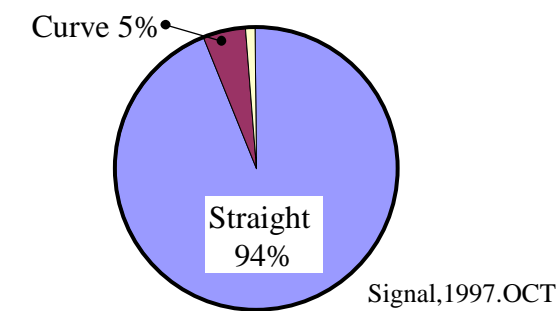


Fig. 4 Road situation during rear-end collision

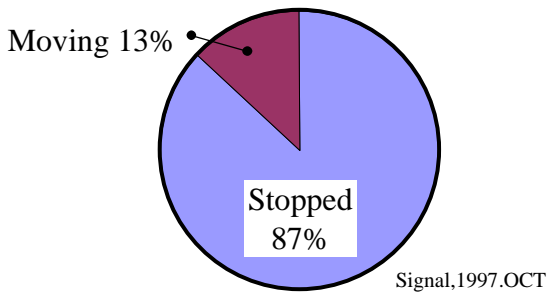


Fig.5 State of leading vehicle during rear-end collision (according to statistics)

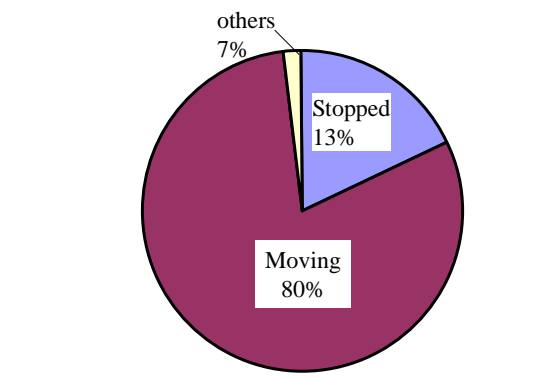


Fig.6 State of leading vehicle during rear-end collision (according to questionnaire)

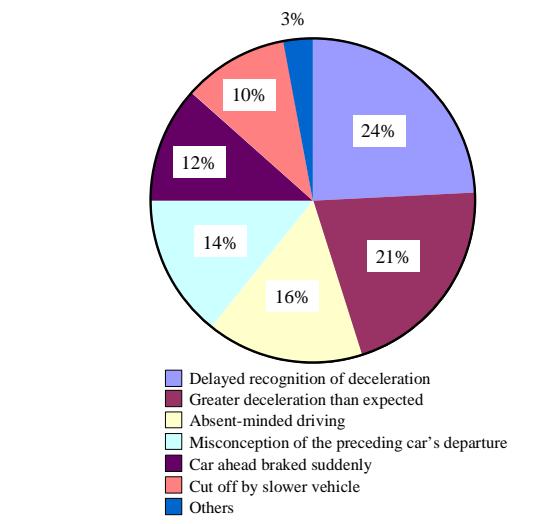


Fig.7 Factors involved in rear-end collisions (according to questionnaire)

Simulation Analysis

It appears inevitable for rear-end collisions to occur when inattention is prolonged for a considerable time due to diminished wakefulness or other such reasons, the large number of accidents makes it unlikely that so many drivers experience such prolonged inattention. The questionnaire survey also failed to uncover such a causal factor.

Consequently, simulation was used to explore the possibility that the accidents could occur due to short-term inattention.

It was supposed from the questionnaire results that the most frequent accident scene involved a driver following behind a moving vehicle, and the leading vehicle decelerated during momentary inattention by the driver.

The conditions were set as follows: The headway time between the leading vehicle and the following vehicle (i.e., relative distance/speed of subject vehicle) was 1.5 seconds. The leading vehicle would decelerate (deceleration of 0.3 G) at the moment when the driver of the subject vehicle was inattentive. After a set period of inattention, the driver would look ahead attentively and undergo recognition, judgment, and deceleration operation.

During this process, the driver's response time (from initial attention to the initiation of deceleration) was set at 1.3 seconds⁽³⁾⁽⁴⁾, and the deceleration was set at 0.8 G during the deceleration operation. The simulation was conducted with three different levels of driver inattention time at 1sec., 1.5sec., and 2.0sec., respectively.

Figure 8. shows the simulation results. The horizontal axis is the velocity of the following vehicle, and the vertical axis is the relative collision velocity.

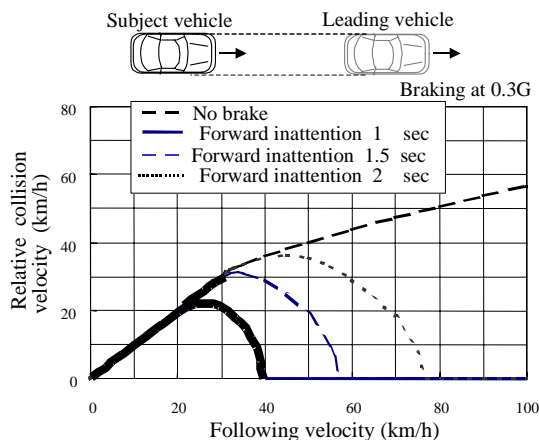


Fig.8 Results of simulation (while following)

It is apparent from **Figure 8.** that, although the length of inattention makes some difference, rear-end collisions take place when cruising at low to medium speeds while at higher speeds the driver decelerates so that rear-end collision does not take place. This result matches the tendency shown in **Figure 2.** for more accidents to occur at low to medium speeds. The bold line in **Figure 8.** shows those cases where the leading vehicle decelerates to a stop, after which the subject vehicle collides it. This shows that rear-end collisions with a stationary vehicle occurs at following vehicle speeds of 40 km/h and below.

In the accident statistics, such cases of rear-end collision with a cruising vehicle that has come to a stop are presented as rear-end collisions with a stationary vehicle. According to this simulation, a rear-end collision occurs while cruising at low to medium speed, and the status is collision with a stationary vehicle. These results, therefore, are in line with the tendencies shown above in **Figure 2.** and **Figure 5.** This also agrees with the tendency found in the questionnaire results, in which the scene of a rear-end collision occurring when cruising behind the vehicle ahead is found frequently. The results in **Figure 5.** and **Figure 6.** were earlier found to be in disagreement. In light of the above, however, this difference can be considered to arise from application of the statistics, and the actual accident scenes represented are similar.

The above simulation results indicate that prolonged inattention alone is not necessarily a major factor in rear-end collisions with stationary vehicles. It was determined that rear-end collisions can occur instead due to momentary inattention while cruising at low to medium speeds.

Forward Inattention Duration While Driving

An eye camera was then used to measure the extent of forward inattention that takes place during daily driving (**Figure 9.**). This measures the length of time that the driver's eyes moved away from the road ahead while the driver carried out ordinary activities such as checking for safety and operating audio equipment under cruising conditions. The horizontal axis shows the time of inattention and the vertical axis shows the frequency. **Figure 9.** makes clear that momentary inattention about 1–2 seconds in duration occurs even during ordinary operations, such as operating the stereo or instrument check. The simulation showed that rear-end collisions can occur if the vehicle ahead decelerates during a period of forward inattention. This may be the reason that many rear-end collisions occur when

cruising at low to medium speeds.

The objective of this research was defined, based on the above analysis, as development of a collision avoidance assist system that would be effective in such a case. The system created was a collision avoidance assist system (rather than a automatic avoidance system) to avoid inviting driver over-confidence, which could be conducive to unsafe driving.

SYSTEM CONCEPTS

Basic Concept

It was learned, from the survey, that there is a braking operation on approximately 70% of the occasions when a rear-end accident occurs or nearly occurs (**Figure 10.**). It is thought that making the driver's braking operation earlier will have the effect of assisting in accident avoidance. Therefore, not simply having brake control immediately prior to a rear-end collision, but by effectively using a warning to bring about early danger recognition and decision-making and then having brake control, it is possible to compensate for insufficient brake force.

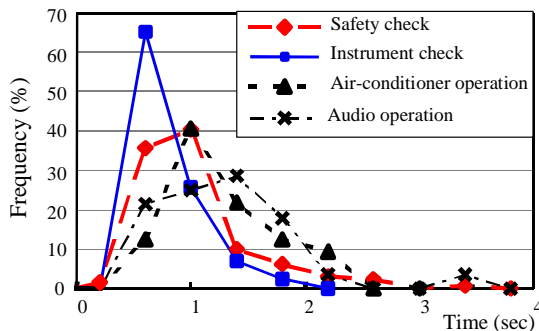


Fig.9 Forward inattention duration

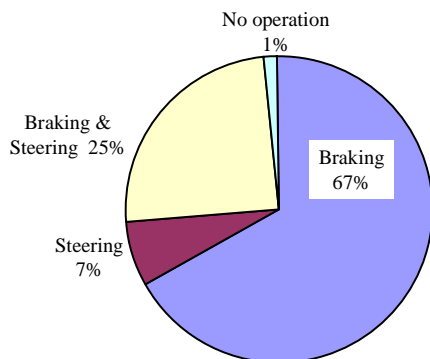


Fig.10 Avoidance operation during rear-end collision

In addition, the brake control timing was established so that the driver does not become dependent on the system, and so that it operates when accident avoidance is very difficult.

Study of Warning Timing

In general, the distance required to avoid collision by using braking only is longer than the distance required to avoid collision by steering operation. Therefore, timing the warning to guarantee collision avoidance using brake control alone may interfere with the driver's avoidance steering operation.⁽⁵⁾

In considering the system's warning timing, therefore, tests were conducted to measure the timing of driver avoidance steering operations. **Figure. 11** presents the measurements of the distance from the vehicle ahead at the point that avoidance by steering is initiated when the subject vehicle is approaching the leading vehicle at a certain relative velocity.

The horizontal axis shows the relative velocity, and the vertical axis shows the distance when avoidance operation is initiated. The various symbols in the graph indicate points at which drivers felt they were performing an ordinary avoidance operation, a somewhat dangerous avoidance operation and considerably dangerous (limit) avoidance operation.

Given the above findings, the following two points regarding the timing for warning issuance were considered for this system. First, the warnings should not sound so frequently that drivers end up becoming accustomed to them, and the warnings lose their original significance. Second, drivers should not be allowed to rely excessively on warnings to the extent that they think it is safe to be inattentive until a warning is issued. With this in mind, the system was set not to issue warnings frequently during ordinary driving, with a primary warning set to be issued with reference to interruption of an ordinary avoidance operation, and a secondary warning timed so that it would be issued to cause drivers to feel they were performing a somewhat dangerous avoidance operation. The timing of brake control was set so that it occurs when rear-end collision avoidance is very difficult, so that it would cause almost no interference with driver operations.

The Concept of Brake Control Settings

The issuance of the secondary warning is timed to interrupt a somewhat dangerous avoidance operation. This is a point where the danger of rear-end collision has grown greater, so

the warning should be definitely recognized by the driver. Therefore, rather than issuing the warning by sound alone, light braking is also applied at the same time in order to convey the warning by physical means. This braking is termed alarm braking. After examination in various ways and using repeated testing, it was determined that the appropriate intensity (deceleration) for the alarm brake was about 0.1 ~ 0.2G. This setting enables an enhanced warning effect to the driver in addition to the sound warning. This is also a setting that will not interfere with operations by drivers who attempt avoidance by steering at that point.

There was a notion that deceleration from the braking (termed emergency braking) that operates just before a predicted collision should be set at the maximum value for brake control, because this was used in circumstances where a rear-end collision was predicted.

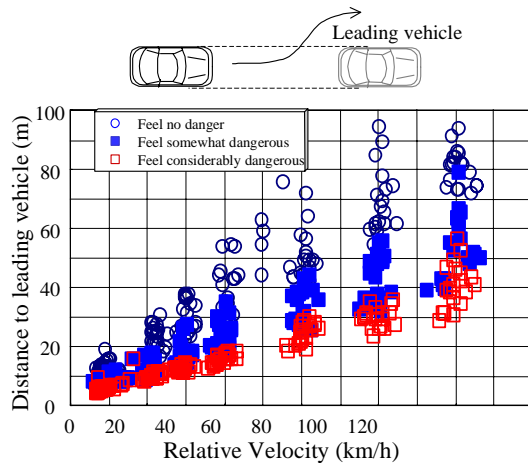


Fig.11 Avoidance operation timing test

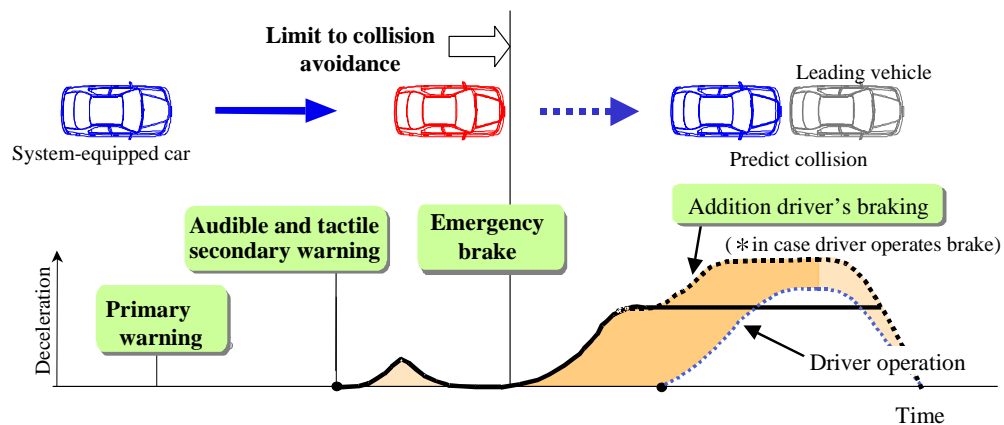


Fig.12 System operation

However, collisions may be avoided by using a combination of deceleration plus steering avoidance operation, to include recognition assistance from a warning sound and alarm braking, deceleration was set with full consideration given to ease of operation. Moreover, the system is configured so that the amount of braking force applied by drivers who recognize danger and apply the brakes will be exerted in addition to the braking force exerted by the system's brake control.

By providing assistance in recognition and decision making through the primary and secondary warnings, this system can be expected to have the effect of facilitation braking operations even for drivers whose response times were previously too slow to allow them to make a judgment and carry out an operation. **Figure 12.** shows the sequence of operational modes.

SYSTEM OUTLINE

System Configuration

Figure 13 shows the system configuration. Millimeter wave radar sensor was equipped as the sensor for forward vehicle detection because of its stable detection performance in different weather conditions. The collision avoidance assist system developed here must be capable of stable operation in a variety of environments. Millimeter wave radar sensor was adopted, therefore, because it is typically less affected by rain, snow, fog, and other such conditions in the natural environment.

Table 1. shows the major specifications of the millimeter wave radar sensor used for the present system. In terms of ranging performance, this radar has the capability to detect a passenger vehicle at 100 m or more. This makes it capable of detection approximately 3 seconds in advance when moving at a relative velocity of 100 km/h.

With a detection area that ranges 16° to left and right, the sensor detects vehicles that are ahead on straight roads and gentle curves.

The system targets stationary vehicles in addition to moving vehicles. Therefore it must distinguish vehicles from many roadside objects such as signs, guardrails, and so on. A scanning type radar sensor is used so that the position of a stationary vehicle can be recognized accurately even in the kind of road environment described above.

The subject vehicle is supposed to measure its own state quantities, and so it is equipped with a wheel speed sensor to measure the vehicle speed, a yaw rate sensor to measure turning, and a steering angle sensor to measure steering wheel operation. The subject vehicle estimates its course as shown in **Figure 14.**, and calculates its estimated lateral travel distance at the obstacle location. In this way, the subject vehicle predicts its own path and prevents false warnings at curves so on.

It is also equipped with an alarm unit that provides warnings to the driver when the system is operating. A hydraulic actuator is also installed in order to carry out brake control. The hydraulic unit utilizes the brake actuator of the vehicle stability assist (VSA) system.⁽⁶⁾ It is equipped with a pressure control valve to allow variation of the braking pressure.

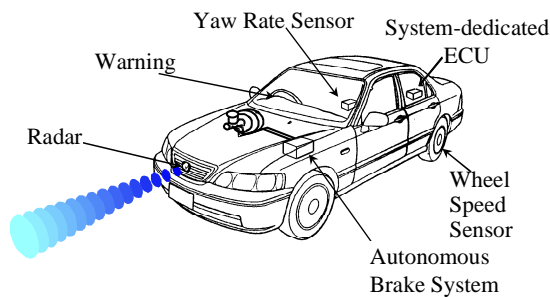


Fig.13 System configuration

Table.1 Major specifications of radar sensor

Frequency	76-77GHz
Wave form	FMCW
Detection Area	Horizontal 16deg
	Vertical 3.8deg
Range	4-120m
Range Accuracy	± 1.0m , ± 5%
Range Rate	± 200 km/h
Range Rate Accuracy	± 5%
Data Update Rate	0.1 sec
Target Tracking	8 Targets
Package Size	106(W)×88(H)×86(D) mm
Weight	0.65 kg

Control Logic

Figure 15. shows the basic control flow. The system recognizes the leading vehicle by radar sensor, and the subject vehicle's path is estimated from its state quantities. Next, the possibility of a rear-end collision is judged, and a judgment is made about the possibility of avoidance by steering. Then, when the danger of rear-end collision is high, the warnings occur, and if the dangerous state continues and avoidance becomes very difficult, emergency braking is carried out.

SYSTEM EFFECTIVENESS

A simulation was carried out on the assumption that the leading vehicle decelerates when the subject vehicle is cruising behind it. The simulation conditions were a headway time of 1.5 seconds when the subject vehicle is following, and a deceleration of 0.3 G by the leading vehicle. The system begins to operate when the danger of rear-end collision is high. The driver is assumed to operate the brakes 1 second after the secondary warning occurs. The deceleration during this driver operation is set at 0.8G. The test results are shown in **Figure 16.** The horizontal axis is the following velocity, and the vertical axis is the relative velocity at the time of collision.

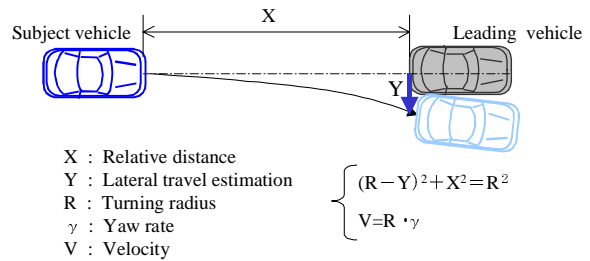


Fig.14 Prediction of the vehicle locus

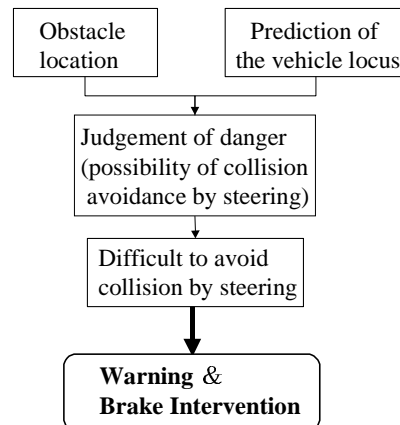


Fig .15 Block diagram of basic control

By providing recognition and decision-making assistance in combination with warnings, it is possible to aid in the avoidance of collisions or to reduce the velocity at which collisions occur.

As shown in **Figure 2.**, the majority of accidents occur at low to medium speeds. Therefore, the system is thought to be useful.

CONCLUSION

A system was developed that is thought to be effective in reducing the collision velocity during rear-end collisions by assisting a driver by means of brake control and external sensing technology using millimeter wave radar sensor.

The following results were obtained:

1. Rear-end collisions can occur during ordinary driving as a result of momentary inattention.
2. A system that prevents interference with driver operation and assists in avoidance operations was created.
3. This system was thought to be effective in reducing the number of accidents at low to medium speeds, which make up the greater part of rear-end collisions.

The present system is above all a collision avoidance assist system intended to assist a driver. It is not an automatic avoidance system. Due to limits in sensing capability and other such factors, the present system is not able to assist a driver against all types of rear-end collision. It is also necessary, therefore, to convey the system limits in clear, understandable terms. In this light, it is important for drivers to recognize the fundamental rule that driving is still their responsibility, as it always has been.

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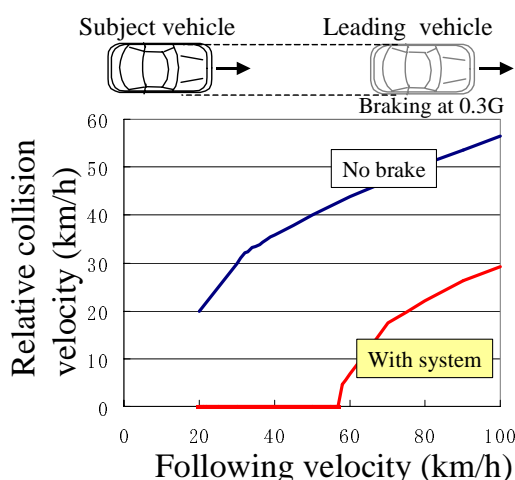


Fig.16 System effect (by simulation)